INDUSTRY INITIATED CORE SAFETY ATTRIBUTES FOR HUMAN SPACEFLIGHT FOR THE 7TH IAASS CONFERENCE

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ABSTRACT

Now that the NASA Commercial Crew Program (CCP) is beginning its full certification contract for crew transportation to the International Space Station (ISS), is it time for industry to embrace a minimum set of core safety attributes? Those attributes can then be evolved into an industry-led set of basic safety standards and requirements.

After 50 years of human space travel sponsored by governments, there are two basic conditions that now exist within the international space industry. The first, there is enough of a space-faring history to encourage the space industry to design, develop and operate human spaceflight systems without government contracts for anything other than services. Second, industry is capable of defining and enforcing a set of industry-based safety attributes and standards for human spaceflight to low-Earth orbit (LEO). This paper will explore both of these basic conditions with a focus on the safety attributes and standards. In the United States, the Federal Aviation Administration (FAA) is now starting to dialogue with industry about the basic safety principles and attributes needed for potential future regulatory oversight. This process is not yet formalized and will take a number of years once approval is given to move forward. Therefore, throughout the next few years, it is an excellent time and opportunity for industry to collaborate together and develop the core set of attributes and standards. As industry engages and embraces a common set of safety attributes, then government agencies, like the FAA and NASA can use that industry-based product to strengthen their efforts on a safe commercial spaceflight foundation for the future.

As the commercial space industry takes the lead role in establishing core safety attributes, and then enforcing those attributes, the entire planet can move away from governmental control of design and development and let industry expand safe and successful space operations in LEO. At that point the governmental agencies can focus on oversight of the industries' defined standards and enforcement for common welfare of the space-faring populous and overall public safety.

CURRENT STATE

At this time, during the summer of 2014, the state of the commercial spaceflight industry self-regulation is still very immature. For human spaceflight, most industry players have continuously looked to NASA and the CCP to drive the design and operational requirements for a LEO system. In the United States there were various opportunities to debate and adjust the draft and preliminary CCP requirements. However, most of the discussion on the CCP requirements were driven around the potential service to ISS, thus becoming a single mission, a single design reference mission type of discussion and debate.

Until recently, the FAA charter has been focused on the regulation of public safety only. Overall, it's an extremely critical element of the aerospace industry's business model. However, it's still a subset of the larger overall package needed for safety attributes for the entire mission cycle of human spaceflight activities. The FAA has begun to package a series of practices for safe human spaceflight in the suborbital and orbital arena. These practices are an excellent start on creating a dialogue for industry and government to synthesize the realm of potential safety requirement or attributes. As the FAA developed its set of practices, it included preliminary input from various industry representatives and from the expertise of NASA and the CCP. The initial release is expected this year and it can be the impetus for further debate within the U.S. commercial

spaceflight industry and, in fact, partnered with the larger international space-faring community.
Organizations such as the International Association for the Advancement of Space Safety (IAASS) and the Commercial Spaceflight Federation (CSF) are also getting involved in discussion and producing some reports on standards and attributes for the industry to debate. These non-governmental organizations are the key to developing and sustaining an industry-based set of safe attributes. In 2010, IAASS published a Space Safety Standard for Commercial Human-Rated Systems [1] for industry to use and debate. CSF is beginning to produce a set of preliminary standards under its organization for its members to debate and discuss.

As the industry moves into the next year, there are copious amounts of information for an attribute-type debate within the community to discuss. As an analogy, the sailing ship of "self-regulation and innovation" has encountered a new stiff breeze and is looking for the opportunity to sail into serious, product debate and discussion within the commercial spaceflight community.

[Image 1]

NASA COMMERCIAL CREW PROGRAM

The ultimate goal of the NASA Commercial Crew program (CCP) is to facilitate the development of a U.S. commercial crew space transportation capability for safe, reliable and cost-effective access to and from low-Earth orbit (LEO) and the International Space Station (ISS). There are three additional objectives to CCP's primary goal. 1) Develop and implement a strategy that stimulates the U.S. space transportation industry and encourages the availability of space transportation services to NASA and others. 2) Mature the design, development, demonstration and certification of U.S. Crew Transportation System (CTS) capabilities. 3) Utilize an alternate business approach by investing in U.S. aerospace industry CTS design and development.
In order to help stimulate the industry, the CCP initiated a series of draft requirements in 2011. Known as the CCT-PLN-1100 [2] series, NASA detailed its set of safety and performance requirements. It was the first comprehensive NASA public set of potential requirements for the commercial human spaceflight industry to use for LEO capabilities. Many of the draft requirements could also be used for a potential LEO services need. However, embedded within the series were a set of common attributes that, over the long run, may be the appropriate contribution to key safety attributes for the industry. The requirements were broken down into top-level safety requirements, with fault and failure tolerance as critical attributes. In addition, an approach to factors of safety, redundancy and human-in-the-loop attributes were also highlighted. The NASA CCP set included a collaborative way to address NASA design standards, whereby NASA identified a set of standards and the elements NASA deemed important within the standard. That allowed industry to bring forward alternate solutions to the NASA standards, which meet the intent of the important elements. Although this approach allows for innovation, it also sets a "bar" for design standards for industry to work toward. In addition, the NASA CCP draft requirements dealt with the necessary processes needed to ensure a proper level of risk management, configuration and flight preparation control. Finally, the draft requirement set addressed operational standards for pre-launch and in-flight operations. This was a first for NASA and the industry to document a set of top-level attributes for operating human space systems in LEO, and makes those attributes available to any U.S. commercial space industry organization. As the NASA CCP effort progressed, the draft set of requirements made to stimulate and encourage innovation and investment in LEO human spaceflight were solidified into a set of approved requirements for the purpose of finishing development work and imminent services for the NASA specific need of ISS crew transportation. Of course at that point the 1100 series moved from a set of attributes and concepts for safe LEO spaceflight to a specific need driven by a contractual element. [4] Industry must now take the effort to the next level of creating its own set of industry-led key attributes for safe suborbital and orbital spaceflight.

FAA ESTABLISHED PRACTICES

The FAA Office of Commercial Space Transportation (AST) has been focused on public safety. Its authority to date is centered on regulations for licensing spaceports and space operators for the purpose of public safety. A common good the U.S. government should be involved with as it protects the general public. Throughout the past few decades, the AST has matured the regulations and enhanced the Commercial Space Launch Act (CSLA) authority. The AST has also been a proponent of a robust and innovative commercial space industry. Many of the recent activities have been focused on expanding and building a robust industry to eventually include, human spaceflight occupant safety. The AST is now developing a document to share its thoughts about established practices for human spaceflight occupant safety. [3] The ultimate goal of the document is to gain consensus among government, industry and academia on established practices as a part of the AST's mandate to encourage and promote continuous improvement of the safety of launch and re-entry vehicles to carry humans. The rule-making timeline is a long and highly regulated process. The purpose of the established practices approach is to encourage dialogue and early discussion within the commercial aerospace community long before the rigid rule-making process begins.

The draft document was released about a year ago and the first official release occurred recently. There are two basic levels of care the document addresses. One is a level of safety needed to help ensure the spaceflight occupants will not experience an environment that could cause death, and second, a level of safety to ensure the system can be operated during critical safety operations.

The established practices framework outlines three key pieces of human spaceflight capabilities: design, manufacturing and operations. The design portion is broken into sections concerning flightworthiness, human systems and interactions, and design configuration and safety. The manufacture portion addresses the continuity of the design into and through the manufacturing and assembly processes. The operations portion addresses planning, procedures, operational system aspects and training.

Similar to the NASA CCP requirements, the AST document also addresses redundancy, structural margins, risk management and operational authority. Unlike the NASA CCP requirement set, the AST approach does not apply to a specific need or design reference mission, but rather to an approach for overall system safety to a human spaceflight system. Integration of the various aspects of the system, its design and operations are included. The document incorporates the critical pieces to the overall level of safety for a human system.
The AST document and approach can be used by industry to promote dialogue and collaboration. The AST approach is the U.S. government's attempt to stimulate that much needed conversation and to encourage industry to take the next step in developing a commercial spaceflight industry-based set of attributes.

[Image 2]

INDUSTRY ASSOCIATIONS

A few industry organizations have also begun to discuss, debate and publish some levels of safety attributes and standards. The most notable to date, is the (IAASS) Independent Space Safety Board publication of a safety standard for commercial human-rated systems. (IAASS-ISSB-S-1700-RevB). It was released in early 2010. The document is a set of standards for any commercial system that intends to have a human rating for both suborbital and/or orbital flight. It is a comprehensive approach to a set

of standards for design and operation of a system. It is broken into three basic areas: technical requirements, vehicle design requirements and certification activities. The technical requirements center around the safety processes and focus on hazardous conditions. The vehicle design requirements focus on redundancy, materials and subsystem parameters. The certification section focuses on hazard analysis and related system safety activities. This effort is a very good start to engage and enhance the safety aspects of a human spaceflight system. Produced by a non-governmental agency, it also moves the discussion in the appropriate direction, to where industry and the industry organizations can lead the future discussions and efforts toward an industry-based set of key attributes.

The Commercial Spaceflight Federation (CSF) within the U.S. has also begun to develop a common set of standards for its members to debate, discuss and eventually support as a part of the CSF organization. The CSF approach is an excellent opportunity for the commercial spaceflight industry to use one of the organizations it initiated to lead the effort of industry-developed safety attributes. The membership of the CSF includes companies interested in both suborbital and orbital flights. In addition, newer companies as well as well-known companies participate in the CSF activities. It is this diverse and innovative set of industry participants who can collaborate in the best way to establish a set of attributes and then use the organization to encourage adherence to those attributes. This approach and leadership by organizations, such as the CSF, and support from international safety organizations, such as the IAASS, can create an enormous momentum shift for the industry and enrich the approach to safe human spaceflight.

[Image 3]

FOCUS AREAS TYPES

There are a number of areas an industry-based set of attributes should concentrate. These areas, in short include: 1) Failure tolerance and redundancy, 2) structural and performance margin attributes, 3) escape systems, 4) configuration control for design of hardware and software, 5) system risk management attributes, 6) operational attributes, and 7) system safety attributes.

Each of these areas need focused attention. In the past, these areas have received differing levels of acceptance within the aerospace industry. In addition, each of these areas has been an area of debate and tension between commercial spaceflight industry partners and government agencies. Without a core set of attributes concerning these areas, the political and social environment surrounding the perception of the commercial spaceflight industry may be hard to overcome.

A description of each of the areas of focus follows:

FAILURE TOLERANCE AND REDUNDANCY

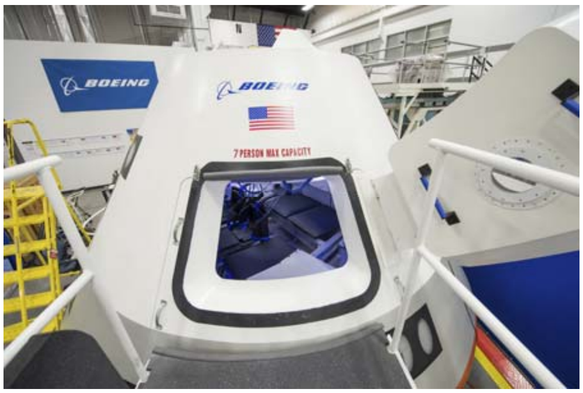
Every design has to weigh the balance between redundancy and performance. The common axiom of "more redundancy equals safer systems" is simply not true. Instead, it is a combination of failure tolerance, redundancy and reliability of the components and subsystems. Therefore, keys attribute of a two-fault tolerant system or single-fault dissimilar redundant system must be balanced with an appropriate and measured level of reliability and criticality of the system. A key attribute led by industry would be an overall failure tolerance capability of the system to protect the crew and occupants and perform a successful mission.

STRUCTURAL AND PERFORMANCE MARGIN ATTRIBUTES

Within the design environment, higher margins usually means more mass and more cost to implement. However, structural margin is a legitimate approach toward dealing with unknown loads and environments on the structure. Therefore, it is critical that some level of structural design margin be applied to designs, especially in the early stages of flight operations and as the environments are being refined and expanded. As a key attribute, a level of structural margin should be included based on the unknowns in the environment of the system and the uncertainty in the design analysis. The traditional level of 1.4 over expected design

operating limits could be an appropriate level if the evaluation of the key attribute is to be fully recognized.

Performance margin can be displayed and appropriated in many different aspects of the design and operation. The key attribute should use a similar process as structural margin in determining a level of margin to account for expected uncertainty and unknowns.



[Image 4]

ESCAPE SYSTEM

The debate over the need for escape systems on space vehicles has been going on as long as there have been humans in space. For many vehicles, an escape system may not be required. However, when there are high risks, including high energy and high dynamic activity during ascent it is a critical piece of the system architecture to include an escape system. The key attribute is to set threshold limits as to when an escape system should be included. It depends on the high energy and high dynamic forces along with the reaction timing that make an escape system a useful core safety attribute.

CONFIGURATION CONTROL FOR DESIGN OF HARDWARE AND SOFTWARE

Core safety attributes are not only in design and components but also just as critical in processes. The best and safest design can be mired by a lack of design configuration control. Therefore, a key attribute is the adherence to a set of standards related to configuration control. That is, what is designed is implemented as designed, assembled as designed and operated as designed. Configuration control is important across all aspects of the system, including vendor design, software, firmware, launch site activities and operational procedures.

SYSTEM RISK MANAGEMENT

Every company and every system have a different level of risk threshold. Even at different times through the system lifecycle the risk tolerance may differ. The key attribute here is not to set a standard of risk tolerance, but to adhere to a flight safety risk approach as an industry. The commercial spaceflight industry as a whole should embrace a set of key risk attributes so all members of the industry can have a level of confidence in the overall risk tolerance. The FAA has a risk level for public safety known as Ec. NASA has an expectation of system safety risk through its Probability Risk Assessment process. For current commercial crewed missions it is loss of crew above roughly 1 in 250. Industry could set itself a key attribute of a threshold and goal for inherent crew and occupant risk and a standardized process to evaluate that risk level.

OPERATIONAL ATTRIBUTES

As a system becomes operational, additional elements are added to the overall design and implementation of the system. Those additional elements include operational personnel, command and communication systems, and data monitoring and interpretation. Training of the personnel not only in the operational systems, but also with a clear understanding of the vehicle systems, its design limits and performance is essential to a safe and cohesive operation of the system. A key attribute concerning the breadth and depth of the type of training needed could be established so that the industry has an appropriate approach to incorporate the operation aspects of the mission into the overall safety level of the system. Again, both the FAA/AST and NASA/CCP have some regulations, requirements and suggestions for the commercial industry to use as starting points for this critical attribute set.

SYSTEM SAFETY ATTRIBUTES

Safe flight is always the goal, but many times the safety process and the system safety approach is an afterthought and not part of the mainstream design process. Throughout the years, tools like Hazard Analysis and Failure Modes and Effects Analysis (FMEA) have been used to connect the design activities to system safety approaches. Many times these system safety tools are “lagging” indicators of the potential design problems and operational usage issues. A key attribute could be the importance of an integrated system safety approach within the design development process and a continuation of the

system safety approach well into operations. The use of the Hazard Analysis and FMEA tools could be emphasized without dedicating an exact method or format for the tool's usage. If the system safety process is embedded in the design and operational lifecycle, it can go a long way toward enhancing credibility with the commercial spaceflight industry.


[Image 5]

CONCLUSION

Safe flight and mission success is the goal of every space adventure and scientific mission. Commercial human spaceflight is no exception. After NASA retired the space shuttle in 2011, an excellent opportunity has opened to allow the commercial spaceflight industry to step in and step up to the role of providing access to LEO for human spaceflight missions. As the U.S. government encourages commercial human spaceflight through the joint development partnerships under the NASA/CCP effort and through the FAA licensing approach for commercial spaceflight, the timing is right for industry to take a lead role in establishing a safety approach for commercial human spaceflight. Fifty years of human spaceflight experience has a large database of knowledge and lessons. The commercial spaceflight industry is now robust enough to support industry-wide organizations that can help promote a safety culture within its ranks. This can be accomplished without government direction, but rather with expertise from all corners of the human spaceflight community. Industry organizations, such as CSF and IAASS, can lead the way to drafting, discussing and eventually establishing a set of key safety attributes that members of the organizations can accept and enforce among themselves. Key attributes in the areas of failure tolerance, margins, escape systems, configuration control, risk, operations and system safety can be developed and used to further develop standards for the commercial spaceflight industry to embrace. The time and the opportunity are perfect for industry instead of governments to lead this activity. By embracing an industry organization approach to safety attributes, spaceflight systems developed and the industry perception and culture of the commercial spaceflight industry can all gain tremendous leaps in maturity as the 21st century evolves.

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